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E. A. BIRGE, Director. C. R. VAN HISE, Consulting Geologist.

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PRELIMINARY REPORT

ON THE

COPPER-BEARING ROCKS

OF

DOUGLAS COUNTY, WISCONSIN.

BY

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INTRODUCTION.

The field examinations which form the basis for this report were made during the summer of 1899. In considering the time available in one season it became apparent that a detailed examination of all the rocks in northern Wisconsin, in which copper might occur, was out of the question. Moreover, we already have a fairly good knowledge of the general geology of this part of the state. It therefore seemed advisable to concentrate the work in certain districts, as a careful study of certain important areas was more likely to produce results of value than the superficial examination of a large area. At the same time it was expected that the future would permit a careful examination of other districts in the state underlain by the copper-bearing rocks. With these points in mind the work of this season was concentrated first on the rocks which lie along, but north of, the St. Croix river in the southwestern part of Douglas county, and second, on those which form the first hill ranges south of lake Superior in the northern part of the county, and in which explorations for copper are being actively prosecuted. The district first mentioned,—i. e., the southwestern, or what is called in this report *the St. Croix copper range,*—presented, in its geological structure, a more simple problem than the northern, or *the Douglas copper range,* and was accordingly examined first.[1]

[1] The northern range has been known as "the South range" and as "the Douglas County range," while the southern has received no name, or has been included with the northern. The two ranges, while alike geologically, are distinct geographically, being separated by a belt of country several miles in width in which there are practically no rock exposures, and it is expedient to have a distinct name for each. The writer understands that the names used above,—Douglas range and St. Croix range,—are coming into use among those interested in the exploration for copper in northern Wisconsin, and these names have been adopted in this report.

This examination was made between the 17th of May and the 20th of June. The remainder of the season, until the last of August, was spent on the northern district. But during this time a visit was made, for the purpose of comparative study, to the copper-mining region of Keweenaw point.

The method followed in the season's field work was to visit all parts of the two areas above mentioned which were known to have rock outcrops, or in which outcrops might be reasonably expected. In such parts north and south traverses were made at intervals of one-half mile, or more frequently when occasion demanded. Thus, in the region where outcrops occur frequently, the north and south section lines, the north and south quarter section lines and some of the east and west section lines were followed. The larger streams, and in fact all the streams which might be expected to cut down to the bed rock, were also followed. The outcrops seen were located carefully by pacing, and the position of each was indicated as so many paces north and so many paces west of the southeast corner of the given section. In this manner of locating 2,000 paces equals one mile. Rock samples were taken from most of these outcrops. In all about 775 rock numbers and a considerably greater number of specimens were collected.

Because of the active interest which is being manifested in the copper deposits of northern Wisconsin, it was deemed best to publish a report on the district without unnecessary delay. Accordingly this report is presented with the hope that it will be of service to those who are at present engaged in exploration for copper, or who are interested in the material development of this part of the state. It should be borne in mind, however, that this report was written before it was possible to make a careful study of the whole district underlain by the copper-bearing rocks, and even before it was possible to make an exhaustive study of the facts and specimens collected in those areas in which the work was concentrated. Thus this report is necessarily of the nature of a preliminary rather than of a final report. At the same time it should be stated that the essential facts concerning the geological structure of the areas examined, the geograph-

ical distribution of the different rocks, the manner of occurrence of the copper deposits, and the general distribution of these deposits have been determined by the work already done. It is accordingly expected that the facts here presented are correct and that future work will tend to confirm rather than to alter them.

It is manifestly impracticable for parties of the Wisconsin Survey to discover every outcrop of the copper-bearing rocks in the state, especially when these outcrops are of small extent, are far removed from each other and are accessible with difficulty. It is therefore requested that individuals, who know of solid ledges of rock anywhere in the northern part of the state, communicate with the Survey, giving as nearly as possible the exact location of these ledges. If convenient, small samples illustrating the rocks should be sent.

Acknowledgements. In the field work the writer was assisted by Dr. C. P. Berkey, Instructor in Mineralogy in the University of Minnesota, who had previously had experience in studying the copper-bearing rocks in the district of Taylors Falls and St. Croix Falls on the St. Croix river. It was exceedingly fortunate that Dr. Berkey's services were available in this work, both on account of his knowledge of the copper-bearing rocks and also because it made it possible to discuss and investigate jointly in the field certain important problems. Mr. Charles Cole, of South Range, and Mr. A. L. Hinman, of Downing, and in the latter part of the season Mr. R. B. McLean, of Superior, acted as compassmen and located all the outcrops seen. Their knowledge of woodcraft and their acquaintance with the county examined aided materially in the season's field work. To the Director of the Survey, Prof. E. A. Birge, and to the Consulting Geologist, Prof. C. R. Van Hise, and to Mr. C. K. Leith the writer's thanks are especially due for a large number of courtesies. The work was undertaken and carried on under the direction of Prof. Van Hise, who spent several days in the field reviewing important points and who was especially helpful in suggestion and advice regarding the work. The analyses were made by Dr. W. W. Daniells, Professor of Chemistry in the Uni-

versity of Wisconsin. One fact became particularly apparent during the season spent in this examination; it was the universal and cordial interest shown in the work of the Survey by the people of Douglas county. Their willingness to coöperate in whatever manner possible was very marked. Among these people was Mr. Ernest A. Arnold, of West Superior, who generously placed his knowledge of the county and a considerable part of his time at the disposal of the Survey.

CHAPTER I.

GEOLOGY OF DOUGLAS COUNTY.

Douglas county is the northwestern county of Wisconsin. It is bounded on the north by St. Louis county, Minnesota, and by lake Superior; on the east by Bayfield county, Wisconsin; on the south by Burnett county, Wisconsin; and on the west by Pine and Carlton counties, Minnesota. Douglas county comprises all those parts of townships 43 to 49, Ranges 10 to 15, which lie in Wisconsin. The total area of the county is 1336 square miles.

PREVIOUS DESCRIPTIONS.

The following are the more important papers which refer to the copper-bearing rocks in this county:

T. C. Chamberlin. "General Geology"; Geol. of Wis., vol. I, pp. 96–118, 1883. "Economic Geology"; Ibid., pp. 656–661.

R. D. Irving. "General Geology of the Lake Superior Region"; Geol. of Wis., vol. III, pp. 7–15, 1880. "The Copper-Bearing Rocks of Lake Superior"; U. S. Geol. Survey, Monograph V., pp. 234–259, 1883.

Moses Strong. "Geology of the Upper St. Croix District" (edited by T. C. Chamberlin); Geol. of Wis., vol. III, pp. 363–428, 1880.

E. T. Sweet. "Geology of the Western Lake Superior District"; Geol. of Wis., vol. III, pp. 303–362, 1880.

The report by Strong deals especially with the St. Croix range; that by Sweet with the Douglas range and gives an account of the earlier explorations for this metal. These reports are out of print. Both ranges are discussed by Irving in "The Copper-Bearing Rocks of Lake Superior."[1]

[1] This book contains the best and most complete account yet published of the copper-bearing rocks in the Lake Superior district and will prove of value to any one interested in the geology of these rocks. It can be procured from the Director of the U. S. Geological Survey, Washington, D. C. The price is $1.85.

SURFACE FEATURES.

The surface of Douglas county, considered broadly, is comparatively level; there are no districts which approach the mountainous, nor are there certain parts which are elevated many hundreds of feet above other parts. When examined in detail, however, this surface presents some marked features and can readily be divided into several distinct zones, each of which is characterized by certain peculiarities of topography. It may be stated that these different topographic zones correspond, in general, to the belts of rock which underlie the glacial deposits. There are five of these topographical zones. They are described below, beginning at the north.

I. That part of the county which borders on lake Superior is a plain. This plain is from five to twelve miles in width and extends from the lake shore southward to the northern edge of the hills which form the Douglas range. The plain slopes gently toward the north, and, while this slope is sufficient for drainage, to the eye the ground frequently appears perfectly level. At the town of South Range, about six miles from lake Superior, the plain is 164 feet above the lake level, and a mile farther south it ends abruptly against the northern flank of the Douglas range. This topographic district is underlain by till and by water-deposited clays which were laid down when the waters of the Lake Superior basin were at a considerably higher level than at present. Beneath these superficial deposits is the Lake Superior sandstone, and the outlines of that formation are the outlines of this plain (see geological map, plate I).

II. The hills which form the Douglas range rise abruptly, from the plain just mentioned, to a height of from 100 to 300 feet. The marked escarpment formed by the northern slope of these hills is a very noticeable feature of the topography, especially when viewed from the plain to the north. This escarpment is analogous to the still more marked escarpment which rises, in Minnesota, from the northern edge of the plain. This hill range, which forms the second topographical district, extends east and west through the county, taking towards the west,

however, a west-southwesterly direction. The hill range is from one to four miles in width, and its southern slope is much more gentle than its northern. On the south it merges gradually into another zone of different topography. The rocks underlying, and very frequently coming to the surface, in this hill range are igneous rocks of Lower Keweenawan age, and in places superimposed on these rock hills are hills of drift, especially in the north half of T. 47 N., R. 11 W., and in the southwest quarter of T. 47 N., R. 14 W.

III. To the south of this hill range and extending nearly to the St. Croix river is a comparatively level tract of land in which prominent elevations are uncommon. Here the ground is frequently so level that extensive swamps exist. This district is underlain by glacial drift, largely in the form of till, while below the drift and rarely outcropping, are the igneous rocks of Lower Keweenawan age.

IV. What are known as "the barrens" form a sandy plateau which stretches northeast and southwest through the county. The surface of this plateau is at times noticeably hilly and is also supplied with depressions in which are frequently lakes. The northwestern border of this tract enters the county near the St. Croix river in T. 43 N., R. 14 W., extends northeastwardly and crosses the eastern border of the county in T. 47 N., R. 10 W. The St. Croix river and the Brule river for a considerable distance flow in the barrens, but near their northwestern border. The southeastern border of the barrens is approximately the same as the southeastern border of the sandstone of the Upper Keweenawan,—in fact the area underlain by rocks of this age is practically the area occupied by the barrens. (See plate I.)

V. The extreme southeast corner of the county, i. e., that underlain by the rocks of the Lower Keweenawan age, is very similar to the third topographic district mentioned above, except that the underlying rocks more frequently outcrop through the till.

The streams of the county are all comparatively young and consequently do not possess broad, deep valleys. The streams of the plain which borders on lake Superior have cut shallow steep-

sided troughs into the unconsolidated deposits which form the surface of the plain. The divides between these streams are wide and flat-topped. Many of these streams head on the northern flanks of the hills which form the Douglas range. The larger streams flow directly across this range, and, where they pass from the range to the plain to the north, have cut noticeable gorges, the most marked of which are along Black river and Copper creek. Commonly along these gorges are rapids or waterfalls. The best known of these is Black River falls (see plate II) which is 110 feet in height. To the south of this plain the streams have very shallow channels. The only exception to this last statement is the St. Croix river, which has cut down 100 or more feet into the unconsolidated drift deposits through which it flows. This river flows in a broad, flat-bottomed valley which is out of proportion to the size of the present stream. The valley was excavated when the St. Croix acted as the outlet for the waters of the Lake Superior basin, the water level of the lake then reaching and overflowing the divide between the headwaters of the present Brule and St. Croix rivers.

SKETCH OF THE DIFFERENT FORMATIONS.

The rocks of Douglas county are readily separable into three distinct series (see geological map, plate I), as follows, in descending order:

Cambrian: Lake Superior sandstone.
Upper Keweenawan: Conglomerates, sandstones, and shales.
Lower Keweenawan: Igneous rocks, largely basic lava flows.

The oldest rocks exposed in the county are of Lower Keweenawan age. They consist of igneous rocks which are almost always basic in nature and which are largely in the form of lava flows. These lava flows, in the northern part of the county, dip toward the southeast or south, while in the extreme southeastern corner of the county are similar rocks dipping toward the northwest. Younger than these and resting directly upon them are a series of conglomerates, standstones and shales of Upper Keweenawan age. Younger still is another series of rocks, mainly sandstones, which outcrop in many places along the southern

Black River Falls. 110 feet high. S. E. ¼ Sec. 21, T. 47 N., R. 14 W.

shore of lake Superior and to which the name Lake Superior sandstone has been applied.

The Lower Keweenawan rocks are the ones which contain the copper deposits.

THE LOWER KEWEENAWAN.

These rocks are of the same age and of the same origin as the copper-bearing rocks of Keweenaw point in which the most extensive deposits of native copper known in the world occur. Moreover, in lithological character the rocks of the two areas are the same in all broad features and in most minor features. The belt of these rocks in the southeastern corner of Douglas county is directly continuous geographically and geologically with the same rocks on Keweenaw point, and the Lower Keweenawan rocks of the northern part of the county are unquestionably continuous, beneath the surface, with those in the southeastern corner of the county (see section AB, plate I).

Sedimentary Rocks.

The only sedimentary rocks which have been reported from the Lower Keweenawan of Douglas county are certain beds of conglomerates lying between lava flows in the southeastern part of the county. These conglomerates are composed of débris derived from the closely adjacent, underlying, igneous rocks. Careful search was made for such conglomerates in the northern belt of Lower Keewenawan rocks, but no indication whatever that such exist was discovered. It is of course possible that such conglomerates do exist here interbedded with the lava flows, and future search may bring them to light. Should they be found, the close parallel in lithology between the rocks of this district and those of Keweenaw point would be practically complete. Moreover, it is known that such interbedded conglomerates exist in this northern belt of lava flows on the Snake river in Pine county, Minnesota, and also on the north shore of lake Superior.

Igneous Rocks.

In general these lava flows are dark colored and basic (i. e., low in silica) in character. To such rocks the non-committal name of *trap* can be conveniently applied. It is not necessary at this place to enter upon a detailed analysis of the different kinds of rocks included under this comprehensive and elastic term, but a few of the commoner types should be mentioned.

The term *diabase* is applied to a rock composed essentially of lath-shaped plagioclase feldspars and of augite, the latter mineral filling in the angular spaces between the feldspars. These rocks are commonly of such fine grain that this relation between the minerals can be determined only by a microscopic examination. Frequently one grain of augite completely surrounds one or more of the feldspars. These augite grains vary in size from very minute ones to those an inch across. When they become of noticeable size and include many feldspars, the rock has a mottled appearance due to reflections from the cleavage faces of the augites, and such a rock is known as a *luster mottled diabase.* Most commonly such rocks contain olivine and are then known as *melaphyres.* The melaphyres become prominent rocks in places, especially in the St. Croix range, where the augite grains are not uncommonly a quarter of an inch across and the feldspars, on account of their color or their minute size, are usually clearly seen only under the microscope.

Gabbro is composed of the same minerals as diabase, but the constituent grains are of approximately uniform size and shape. The gabbros found in Douglas county are usually of considerably coarser grain than are the rest of the Keweenawan rocks.

A *porphyry* is a rock which contains crystals of one or more minerals imbedded in a groundmass which is of much finer grain when compared with these porphyritic crystals.

An *amygdaloid* is a rock which contains roundish cavities which have been more or less filled by secondary minerals. These cavities are due to gas which escaped from the molten lava on cooling. They vary in size from those of microscopic dimensions to those which are an inch or more in diameter.

The minerals which occur most commonly in such cavities are quartz, calcite, epidote, chlorite, and prehnite. Native copper also occurs.

The last two names,—porphyry and amygdaloid—are textural terms and are also applicable to acid (i. e., those high in silica) igneous rocks, but such are rare in Douglas county. The acid rocks seen are granites, syenites, and quartz-porphyries. *Granite* is composed of quartz and orthoclase feldspar with one or more of the following minerals: mica, hornblende and augite. The grains are of approximately uniform size and shape and the rock is in general coarser grained than the ordinary traps. *Syenite* is the same as granite except for the lack of quartz. *Quartz-porphyry* is a porphyry which has porphyritic crystals of quartz and the mineral composition of granite.

Most of the rocks of the Lower Keweenawan are in the form of lava flows and almost all of these are basic in character. In only one place (on Copper creek) were lava flows seen which approached an acid composition. Quartz-porphyry, however, undoubtedly exists in small quantities associated with these basic lava flows, for a few pebbles of such rock occur in the conglomerate at the base of the Upper Keweenawan. Whether this quartz-porphyry exists in the form of lava flows or intruded masses is not known. A few of the diabases, and possibly some of the melaphyres, occur as intruded sheets or dikes in the surrounding lava flows, and the gabbros, granites, and syenites are all intrusive. These intrusive rocks are most common along parts of the Aminicon and Middle rivers in the northern half of T. 47 N., R. 12 W., and the southern half of T. 48 N., R. 12 W.

Basic Lava Flows.

We are accustomed to think of lava flows as coming from volcanic mountains. In such a case the different flows from any one volcano would be arranged in roughly concentric belts dipping away in all directions from the central mountain. But in the flows here considered there is no such arrangement. They extend over long distances with comparatively uniform thick-

ness and dip and strike. There are no evidences of volcanic mountains. It is therefore commonly thought that the lava flows of the Lower Keweenawan came, not from one volcanic mountain nor from a series of such, but from extensive fissures in the earth's crust. In no other manner can we account for the uniform thickness, dip and strike of these lava flows over long distances. From these fissures welled out molten material which flowed away as far as the slope of the surface and the rapid cooling of the mass permitted. After each flow there was a longer or shorter period of inactivity followed by another flow. Thus there was built up, flow upon flow, a vast thickness of igneous rock.

The different flows vary much in thickness, and even the same flow may vary in thickness from place to place. The thinnest flows seen had a thickness of about two feet, and from this size there are flows of various thicknesses up to those of a hundred or more feet. The larger flows are more continuous, both along the strike and also along the dip, than the smaller. At times these larger flows can be traced along the strike for several miles. One of the belts of melaphyre, which appears to be all one mass of rock, on the St. Croix range can be seen at intervals for a distance of over twenty-two miles.

Dip and Strike. The original angle of slope of these flows undoubtedly varied, but the average was a smaller angle than they now have. Thus it is seen that the whole series has been tilted somewhat from its original position. This is especially true of the rocks of the Douglas range where the dip varies from 30° to nearly vertical. The dip on the St. Croix range is lower, averaging less than 20°. On both ranges the dip is toward the south or southeast. The strike on the Douglas range is about northeast near the western end, but, on going eastward, gradually assumes a higher angle with the north, and at the eastern end of the range it is east and west.

Separation of the Different Flows. The copper deposits of the district are usually found at the top of one flow or at the bottom of the next overlying flow. From the fact that the copper deposits occur thus,—as it were between two flows,—it be-

comes a matter of prime importance to be able to distinguish one flow from another and to determine where one flow ends and the next overlying one begins. This is not only of importance in the search for copper, but is also of value in determining the sequence, dip, and strike of the flows and the general geological and structural features of the region. Some of the characteristics by which one flow can be separated from another are given below:

I. Two flows may differ by certain features, such as color, coarseness of grain, mineral composition, hardness, texture, absence or presence of porphyritic crystals or of amygdules, or one may be affected more by the weather than another. Where two or more, or at times even one, of these features markedly differ in two adjoining flows, the separation is easily made.

II. Each flow is of finer grain at the bottom and at the top than in the center. This is not especially marked in those flows of only a few feet in thickness, but in the thicker flows this feature is found to be quite prominent when a careful examination is made. Commonly in the central parts of the thicker flows the different grains can be easily distinguished by the unaided eye, while it is very usually the case that on going from the center toward the upper and lower parts of the flow, the grain gradually becomes finer until the different grains can be distinguished only by a microscopic examination. On the upper surface the rock may become even glassy.

III. In most of the flows amygdules are developed near the upper surface, and, much less commonly, amygdules of smaller size than those near the upper surface are seen near the lower surface. Some of the thinner flows are amygdaloidal from bottom to top. It is the rule, however, that the upper few feet,—from two to ten or even twenty feet,—of a flow is amygdaloidal and that the amygdules decrease in size and number as you go farther from the upper surface. This presence of the amygdaloidal texture in the upper part of a flow is one of the commonest criteria by which two flows can be separated.

IV. The upper part of a flow frequently presents a fragmental appearance. This may be due: (1) to a breaking-up

of the hardened upper crust of a flow by the onward movement of the still liquid mass beneath, the result being a confused mass of fragments cemented by rock of nearly the same nature; (2) to a breaking-up of the upper surface of a flow by the elements, and its subsequent cementation by its own debris or by the next overlying flow; (3) to volcanic fragmental deposits,—bombs and ashes,—deposited on the surface of one flow during the interval between its consolidation and the extrusion of the next flow. This fragmental upper part of a flow, when present, varies in thickness from an inch up to several feet. The fragmental character of the upper portion of one of these flows is shown in plate III.

V. The upper surface of a flow may show a ropy structure or other peculiar surface structures,—structures which are common to the surfaces of many lava flows, but which are not frequently seen in the old lavas here considered.

VI. In the adjustments which took place between the different beds in the tilting of these rocks from their original positions fissures were formed, and these would form in the weakest planes of the rock, i. e., in the loosely textured upper part of the flow or along the division line between two flows. Such a fissure is frequently accompanied by a more or less marked brecciation of the walls of the fissure. This criterion cannot be relied upon when all other criteria are absent, but it is of value as one feature which, in connection with others, helps to establish a division between two flows.

VII. One marked feature of the topography in districts where the Keweenawan rocks are not covered by later material is a peculiar step-like surface. The different steps vary in size according to the thickness of the individual flows, some of the smaller steps being shown in plate III, and one of the larger ones in plate IV. This step-like character presents itself as follows: When one approaches from the north a ridge composed of outcrops of several flows he first encounters a very steep, northward-facing slope, or even a precipitous wall, which indicates, nearly, the thickness of the lowest flow. At the top of this wall is a gentler slope to the south, the slope coincid-

ing practically with the dip of the rocks and marking the upper limit of the flow approximately but not exactly, for usually some of the loosely textured upper part of the flow has been removed by erosion, glacial or otherwise. On following down this slope for a short distance another very steep slope, or precipitous wall, is met, beyond which the more gentle southern slope and the steeper northward facing slope is repeated indefinitely. Many of the ridges on the Douglas range show this peculiar step-like outline. Where the flows are quite thick valleys, elongated in the direction of the strike, mark the separation between two flows. A typical case of this kind is illustrated in plate IV, the slope on the left indicating the dip and approximately the upper surface of one flow, while the steep wall on the right marks approximately the thickness of the next overlying flow.

THE UPPER KEWEENAWAN.

The Upper Keweenawan rocks form a broad belt which extends northeast and southwest through the southeastern part of the county (see geological map, plate I). They are flanked on both sides by the Lower Keweenawan rocks. The strata of the Upper Keweenawan are of sedimentary origin and consist of conglomerates, sandstones, and shales. The only places where rocks of this age have been examined by the writer are at certain localities along the St. Croix river and its tributaries in Ts. 44 N., R. 13 W., 43 N., R. 13 W., and 43 N., R. 14 W. (For location of outcrops of rocks of this age, see plate VII.) Here the conglomerates, which are interbedded with, and succeeded upwardly by the sandstones and shales, lie apparently conformably on the underlying igneous rocks and dip toward the southeast at angles of from 10° to 18°. The strike is almost exactly northeast.

On the lower part of Crotty brook, near the center of the west side of Sec. 8, T. 43 N., R. 13 W., there is a considerable exposure of rocks of Upper Keweenawan age. They consist of interstratified conglomerate, sandstone and shale, all reddish brown in color. The pebbles of the conglomerate are of all

sizes up to six inches in diameter and are well rounded. They consist of fine grained igneous rocks similar to rocks which are known to occur in place a mile or more to the northwest, with the exception of some pebbles of quartz-porphyry which rock is not known to outcrop in this vicinity. The matrix of the conglomerate is sandstone cemented at times by calcite, and this matrix and the purer beds of sandstone do not, except in very small part, consist of quartz sand, but of material which was derived from basic igneous rocks. The strike is N. 45° E. and the dip 12° to 14° to the south of this. On the same stream, near the center of the east side of Sec. 7, T. 43 N., R. 13 W., is a small exposure of conglomerate. Farther up the stream are no other exposures of sedimentary rocks, but fragments of conglomerate are rather common nearly up to the traps which occur in the northwest quarter of the same section. The boundary of the Upper Keweenawan is thus most probably very close to the most southern of these trap outcrops.

On the Moose river the most northerly exposure of conglomerate is on the east side of the river and close to the south line of Sec. 14, T. 44 N., R. 13 W. This is a small exposure, but directly across the river is an exposure of trap, thus allowing the division line between the two parts of the Keweenawan to be located with precision at this place. On the west bank of the river, a short distance below the outcrops just mentioned, are other outcrops of conglomerate interbedded with a sandstone which forms the matrix of the conglomerate. The pebbles here are of all sizes up to those fifteen inches in diameter, and practically all, except some half an inch or less in diameter, are well rounded. The pebbles are of trap of various kinds, but among them no melaphyre nor quartz-porphyry was found. The sandstone is of yellow color and consists of fine fragments of the traps cemented by epidote and calcite. The strike is approximately N. 40° E., and the dip 13° to the south of this. Exposures of conglomerate and interbedded sandstone continue at intervals down the river almost to the bridge which is in the S. E. ¼, S. E. ¼, Sec. 27, T. 44 N., R. 13 W. The sandstone varies in color from yellow, through gray, to brownish red.

Third Flow.

Second Flow.

First Flow.

Upper surface of Lava Flow. S. E. ¼ Sec. 2, T. 47 N., R. 13 W.

Valley between two Lava Flows. S. E. ¼ Sec. 2. T. 47 N., R. 13 W.

THE LAKE SUPERIOR SANDSTONE.

All of Douglas county north of the Douglas range is underlain by this sandstone. Outcrops along the Lake Superior shore in Douglas county have not been reported, but the larger streams have at times cut down through the glacial and lacustrine deposits to the underlying sandstone; this is especially the case near the southern border of the sandstone area. Outcrops also occur on the St. Louis river at the northwestern corner of the county.

The sandstone lies nearly horizontal. Toward the southern border there is a slight dip toward the north and in close proximity to this border, as will be mentioned below, the sandstone is in places much disturbed.

In lithological character the Lake Superior sandstone, at least as exposed in Douglas county, is decidedly different from the sandstone of the Upper Keweenawan. The latter is a sandstone composed of fragments of basic igneous rock while the former consists essentially of quartz sand. In a few places, as at the contact with the traps on the Black and the Aminicon rivers, the lowest exposed strata of the Lake Superior sandstone consist of a conglomerate, and at the former locality the conglomerate contains, in addition to the pebbles of basic igneous rock, a considerable percentage of quartzite pebbles. Some of the higher strata of the Lake Superior sandstone are rich in clayey material and some layers are typical shales. In color the sandstone varies from white to reddish brown, and frequently in small areas there is much mottling due to these two colors.

JUNCTION OF THE LAKE SUPERIOR SANDSTONE WITH THE TRAPS.

The junction of the Lake Superior sandstone with the Lower Keweenawan is marked by a distinct fault. On the north side of this fault line the strata have been relatively depressed, while on the south side they have been relatively elevated. We thus find the Lake Superior sandstone, which is younger than the traps of the Lower Keweenawan and originally overlay them, today at a lower horizon than the traps. The actual

amount of displacement along this fault line has not been carefully determined, but in some places it is probably several hundreds of feet.

The rocks on each side of the fault have been affected differently by this displacement, as described below.

Effects on the Traps.

Along the fault line the traps have been remarkably shattered. This shattering becomes more prominent, and the fragments into which the rocks are broken become smaller, as the contact line is approached. The marked brecciation of the traps commonly extends, not only for a few feet from the sandstone contact, but to a distance of 400 feet or even farther. The extreme fineness of this brecciation is a very marked feature. In many outcrops the traps are seen to be so thoroughly shattered that it is impossible to find a fragment of the rock more than an inch across which is not divided into smaller pieces by cracks. On weathering, or by a blow from the hammer, such a rock breaks down in small, angular pieces. One good example of this brecciation of the traps near the sandstone contact is shown in plate V.

The displacement which occurred along the fault is thus seen to have been distributed, at least in part, through a considerable thickness of rock, so that the fault plane is, in this case, a "plane" which is a number of feet in thickness.

This brecciation of the traps, together with the marked topographic break which occurs at the junction of the sandstone and traps, becomes an important aid in determining the northern border of the Keweenawan rocks and thus the line north of which explorations for copper need not be carried. There are other places where the traps have been brecciated, as already mentioned, but here the brecciation is commonly confined to the line between two flows and the brecciated mass is at most only a few feet in thickness.[1]

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[1] See under VI on page 14.

Fault Breccia in the Traps. Middle river contact of Traps and Lake Superior Sandstone.

Effects on the Sandstone.

As a rule the sandstone does not show this marked brecciation near the contact. Only in one place,—at the Middle river contact in Sec. 25, T. 48 N., R. 12 W.,— does the sandstone exhibit evidence of so complete a shattering as do the traps. But the sandstone has been affected in a different manner and has been thrown into folds, or broken into large, faulted blocks.

Black River Contact. For a short distance below Black River falls the river flows in a gorge cut in the traps, but within 800 feet of the falls the Lake Superior sandstone occurs in a few isolated exposures. These dip in various directions, and in one place strata of the sandstone are found included in the trap breccia which exists near the contact line. Some 200 feet farther down the river the sandstone is exposed more continuously and near the contact the dip is 35° toward the north. Farther north the dip becomes less and the sandstone, except for a few minor undulations, becomes practically horizontal. The general effect on the sandstone at this contact is a bending upward of the beds near the fault line, while in the immediate vicinity of the contact there has been some faulting of the sandstone.

Copper Creek Contact. Here, on the west bank of the stream, the two rocks occur within ten feet of each other. The trap shows a precipitous wall facing north and rising some fifty feet above the stream, and ten feet to the north of this is an exposure of sandstone rising fifteen feet above the water. The sandstone dips toward the north an at angle of 60°, while a few feet farther from the contact the dip is 40° toward the north, and within a distance of 100 feet from the contact the sandstone has become practically horizontal. The bending upward of the sandstone beds at this contact is represented in the section on plate VIII.

Aminicon River Contact. Here the contact plane, as exposed, dips to the south at an angle of 45°. At the contact the sandstone has been sharply flexed upward and also probably faulted. Within forty feet of the fault plane the sandstone is nearly hori-

zontal and continues so, with the exception of a few minor irregularities, to the sandstone quarry, about half a mile to the northwest. See section AB on plate IX.

Middle River Contact. The contact between the sandstone and the traps is crossed three times by this river in Sec. 25, T. 48 N., R. 12 W., and the exposures are such as to render this contact of more interest than any of the others. The upper layers of the sandstone, as seen here, are shaly sandstones or red and gray shales with some bands quite rich in lime. In the immediate vicinity of the traps the shaly sandstone is very much brecciated, to as high a degree as the brecciation of the traps before described.[1] The sandstone has been thrown into a marked series of folds, so that the dip is, for a distance of nearly half a mile from the contact, at a high angle toward the south. This dip varies from practically vertical near the contact to 40°, the average in this half mile being nearly 70°. (See plate VI.) At the contact there is perhaps a sharp synclinal fold so that for a few feet the dip is toward the north. Beyond this half mile (i. e., to the north) exposures are not very continuous, but such as occur show first flat dips, dips of from 40° to 60° toward the north, dips of 20° toward the south, and lastly horizontal strata. All these occur within a mile and a quarter of the contact. The section CD, on plate IX, shows the folding of the rocks as above described.

THE LATER FORMATIONS.

In Douglas county there are no strata known which are younger than than the Lake Superior sandstone and older than the glacial drift. No attempt was made in the examination of the copper-bearing rocks to investigate the drift deposits of the county. It is only necessary to state that the glacial deposits take three distinct forms: (1) unstratified drift or till which exists largely in the second, third, and fifth topographic districts already described;[2] (2) stratified drift, which exists in the barrens or the fourth topographical district; and (3)

[1] See p. 18 and plate V.
[2] Pp. 6–7.

Tilted strata of Lake Superior Sandstone. Middle river, contact of Traps and Lake Superior Sandstone.

clays deposited near the end of the Glacial epoch in the Lake Superior basin. These are underlain by, and mingled with, the unstratified drift and the two together form the marked red clays which cover the northern part of the county.

GEOLOGICAL STRUCTURE.

To the statements already made it is only necessary to add that the structure of the Keweenawan rocks is that of a syncline, with the synclinal axis running northeast and southwest through the center of the tract underlain by the rocks of Upper Keweenawan age. To the southeast of this axis the strata dip northwest, while to the northwest of it the dip is toward the southeast and south. This fold is a very open and shallow one, the dips near the center being small, while on the edges they become more steep, here averaging perhaps 40°. (See section on plate I.)

The junction between the Keweenawan traps and the Lake Superior sandstone on the north is marked by a fault, as has already been described. The sandstone dips at a very low angle toward the center of the Lake Superior basin, or is practically horizontal.

Joints.

Intersecting the strata of the Keweenawan, both the sandstones and the traps, are frequently joint planes. There are commonly two series of these, one coinciding practically with the dip and the other at right angles to the first and running with the strike. There are also frequently joints of another system which are practically at right angles to those of the first system and run with the direction of the dip. In outcrops where the dip and strike cannot be definitely determined these joints, especially those of the system which coincides with the dip, give an indication, but not always a reliable one, of the dip and strike.

GEOLOGICAL HISTORY.

In a very early period (Algonkian) of geological time, but later than the deposition of the rocks which contain the iron ores of the Lake Superior district, Douglas county was being covered by successive flows of molten rock. These flows were built up, one on top of another, until a mass of igneous rock several thousands of feet in thickness had accumulated. These are the rocks of the Lower Keweenawan age. These flows at last ceased and were followed, without any great lapse of time, by the deposition of a series of sedimentary rocks of Upper Keweenawan age. These sediments lie above and conformably upon the older lava flows, and consist essentially of material derived directly from these lava flows. After the deposition of these sedimentary rocks the land was raised above sea level, where it stood, exposed to erosion, for a long period of time. Some time after the deposition of Upper Keweenawan rocks, and quite probably accompanying the elevation of these rocks above the sea, compressive forces acting in a general northwest and southeast direction flexed the strata into their present synclinal form (compare section AB on plate I). Later the region, or at least the northern part of it, was again covered by water, and in this water were deposited the strata of the Lake Superior sandstone. These strata are of Cambrian age and were deposited in an approximately horizontal position,—a position they have largely retained to the present day. At some unknown time after the deposition of the sandstone the district was visited by an east and west fissure, along which there was a displacement of the rocks. This is the fault already described which at the present time separates the Lake Superior sandstone from the Keweenawan traps. The downthrow was on the north side of the fault line.

During all the long ages which have elapsed from the time of the Lake Superior sandstone (Cambrian) until the present day Douglas county seems to have been above water,—at least there are today no remnants of strata younger than the Cambrian. It is possible, of course, that such strata might have been deposited

and afterwards removed by erosion. The glacial deposits which now so universally cover the bedrock throughout the county owe their origin to the ice sheet which covered the northern part of the United States in, as it were, the geological yesterday.

GEOLOGICAL MAPS.

Accompanying this report are four geological maps. The first (plate I) is a general geological map of Douglas county. The others (plates VII, VIII and IX) are more detailed maps of limited areas. The extent of each of these detailed maps is indicated on the map of Douglas county. On the detailed maps practically all of the data (except the topography and such features as the abundance of certain kinds of boulders) which the Survey depends upon in locating the boundaries between the different formations are presented. The maps then will enable one to tell at a glance how accurately the boundary lines between the different formations are drawn, the accuracy being a direct function of the amount of information at hand. This feature of the maps will appeal directly to those who are interested in exploring or selecting copper lands. For example, a given "forty" can be seen to be positively without or positively within the area underlain by the copper-bearing rocks; or it may be on or near the border line, in which case the map will give the evidence as to whether the boundary line is here located with definiteness, and the consequent probability of the given "forty's" being on the copper range.

Along the north boundary line of the copper-bearing rocks in plates VIII and IX the topography (i. e., the marked escarpment at the northern limit of the Douglas range[1]) and the intense brecciation of the traps near the contact line[2] made it possible to locate the limit of the Keweenawan traps much more carefully than the maps indicate on their faces, for these two features are not represented. However, in T. 48 N., R. 11 W., on account of the scarcity of the exposures and the lack of the marked escarpment, this boundary line is much less definitely located than elsewhere on these two maps.

[1]See II on p. 6.
[2]See p. 18.

On the county map (plate I) outside of the areas of the detailed maps the geological boundaries have been located by information obtained from different sources. The north boundary of the Lower Keweenawan in T. 46 N., R. 15 W., is taken from the maps of the former Geological Survey of Wisconsin. The southeastern boundary of the Lower Keweenawan northeast of the area shown in plate VII is not definitely located because of the lack of outcrops. The only rock exposures noted by the parties of the Survey in the vicinity of this boundary line are some knobs of coarse melaphyre in Sec. 15, T. 45 N., R. 12 W., at the "rock cut" on the C., St. P., M. & O. railway in Sec. 12 of the same township, and near the northeast corner of Sec. 31 and the southwest corner of Sec. 29, T. 46 N., R. 11 W. The boundary between the Upper and Lower Keweenawan in the southeastern corner of the county is located from the work of the former Geological Survey of Wisconsin,[1] from a map by Irving,[2] and from information kindly furnished by Prof. J. A. Udden, of Rock Island, Illinois.

On the detailed maps (plates VII, VIII, and IX) the occurrence of copper ore,—the native metal, or carbonates, or sulphides,—is indicated only in those localities where parties of the Survey have actually seen it. Copper has been reported from other localities, and farther search will undoubtedly reveal many more.

[1] Moses Strong. "Geology of the Upper St. Croix District;" Geol. of Wis., vol. III, pp. 363-428, 1880.

[2] "The Copper-Bearing Rocks of Lake Superior;" U. S. Geol. Survey, Mon. V, plate 1, 1883.

CHAPTER II.

THE ST. CROIX COPPER RANGE.

This name is applied to the belt of copper-bearing rocks which are exposed just to the northwest of the St. Croix river in the southwestern part of Douglas county. The part of this range about which we have the most information is shown on the accompanying geological map, plate VII. Outside of the area shown on this map exposures are not common except along certain parts of the Tamarack and Spruce rivers in T. 43 N., R. 15 W. A few exposures are also known in Secs. 28, 29, and 32, T. 44 N., R. 14 W., and near the south side of Sec. 6, T. 43 N., R. 14 W.

The igneous rocks here exposed are readily separable into basic lava flows of slightly varying characters and coarse melaphyres. The presence of the latter rocks make it possible to divide the area into a number of parallel belts which trend northeast and southwest. The melaphyres, on account of the greater thickness of the beds and the more resistant character of the rock, outcrop more frequently than the thinner-bedded and softer lava flows. These harder rocks commonly form low ridges, and by means of these ridges the melaphyre belts can often be traced when outcrops are very few. These ridges can be distinguished from drift ridges by their straight outlines, their uniform southwest and northeast trends, their steep northwestern slopes and their more gentle southeastern slopes. Some of the finer grained melaphyres are distinct flows, having a markedly amygdaloidal upper surface, but the nature of others is not so clear. It is not improbable that some of the coarser grained melaphyre belts are intrusive sheets, but in no case has it been possible to establish this.

SPECIAL DESCRIPTIONS.

Below are descriptions of some of the more important outcrops. The locations of all of the outcrops known in the most important part of the range can be seen by consulting the map, plate VII.

T. 46 N., R. 11 W.

The most northeasterly exposures known to the Survey on the St. Croix range are two in the S. W. ¼ of Sec. 29 (240 paces N. and 1,875 W., and 640 N. and 1,795 W.). They are of melaphyre. Near the northeast corner of Sec. 31, and extending to the north line of this section 160 paces west of the northeast corner, is a marked ridge of the same rock. This ridge runs southwest from this locality for a distance of about 400 paces, and has a precipitous northwestern face from 50 to 80 feet in height. The exposures in these two sections undoubtedly represent but one belt of melaphyre.

T. 45 N., R. 12 W.

At what is known as "the rock cut" on the C., St. P., M. and O. railway, near the center of the west side of the N. W. ¼ of Sec. 12 (1,200 paces N. and 1,850 W. to north end of cut), there is a cut extending 215 paces through a ridge of melaphyre. A few small seams exist in the rock. In one of these a very small amount of native copper was seen. Near the center of the south half of Sec. 15 (400 paces N. and 1,120 W.) is another exposure of melaphyre.

The exposures mentioned above are all that are known to the Survey in Ts. 46 N., R. 11 W., and 45 N., R. 12 W. It is very probable that all these exposures belong to one melaphyre belt.

T. 45 N., R. 13 W.

In the S. W. ¼ of Sec. 25 (50 paces N. and 500 W.) is a large exposure of melaphyre. This is a continuation of the most northwesterly belt of melaphyre shown on plate VII. On the

Moose river near the southeast corner of Sec. 14 (50 paces N. and 60 W.) is a decayed reddish trap. On the same river in the S. W. ¼ of Sec. 13 (125 paces N. and 1,700 W. and extending to 65 N. and 1,600 W.) are exposures of amygdaloidal traps.

T. 44 N., R. 13 W.

Moose River. The most southerly exposure of igneous rock on this river is on its west bank near the south side of Sec. 14 (130 paces N. and 540 W.). The rock is a fine grained, somewhat luster-mottled, amygdaloidal diabase. The amygdules contain quartz, chlorite, epidote, and calcite. In irregularly outlined areas the rock is highly charged with epidote, and in some of these areas is a small amount of native copper. The rock is cut by a few small, red flinty, vein-like forms and where these cut the epidotized areas the veins sometimes carry a little copper. This flow represents the youngest, or almost the youngest, of the Lower Keweenawan rocks in this vicinity, for just across the river occurs a conglomerate of Upper Keweenawan age.

Several other exposures occur along the river in this section; one of these (675 paces N. and 925 W.) is of much interest. It is on the west bank, near the water's edge, and consists evidently of only one flow. It is a reddish, amygdaloidal diabase, which in its coarsest parts is luster-mottled. At the southern end of the exposure is a highly epidotized part of the rock which is two feet in width, runs northeast and appears to stand in a vertical position. It can be traced for only a few feet and disappears under the soil on one side and under the water on the other. In the amygdules and cracks in this epidotized part of the rock is a considerable amount of native copper.

In Sec. 2, on the south bank of the river, is an outcrop of an amygdaloid (385 paces N. and 190 W.) which contains large porphyritic crystals of reddish feldspar. Such porphyritic amygdaloids are rare on the St. Croix range. In the same section, at a marked bend in the river, is a series of at least three highly amygdaloidal flows (580 paces N. and 750 W.). Farther

up the stream in Sec. 2 on the west bank, is a low ledge (765 paces N. and 870 W.) which is poorly exposed and lies mainly under the water. The rock is a hard, dark reddish amygdaloid. The amygdules are filled by quartz, chlorite, calcite, prehnite and native copper. The ledge is about eight feet in width and seems to be copper-bearing throughout. The water rendered a careful examination of this ledge impossible. This is a favorable place for exploration, as a comparatively small amount of work would give more definite information concerning the worth of this copper-bearing layer.

Crotty Brook. Several exposures exist along this stream in Secs. 30 and 31. The most northerly exposure in Sec. 30 (1,400 paces N. and 880 W.) is on the west bank. The rock is a reddish amygdaloid and in it are a few seams and small highly epidotized areas, both of which at times carry a little native copper.

T. 43 N., R. 13 W.

Crotty Brook. The most southerly exposure of igneous rock on this stream is in the N. W. ¼ of Sec. 7 (1,420 paces N. and 1,565 W.). This is near the top of the Lower Keweenawan.[1] The rock is a reddish diabase which is distinctly luster-mottled in the center and lower part of the flow, but is amygdaloidal near the upper surface. In this amygdaloidal portion are some irregularly outlined masses of roughly spherical form and from two to ten inches in diameter. These masses appear to be parts or the ordinary rock which have been highly charged with epidote, and some of them contain small amounts of native copper. Farther up the stream, but in the same quarter section, are other exposures of amygdaloid cut at times by small vein-like forms of reddish, hard, flinty rock which occasionally carries small specks of copper. In one of these amygdaloids (1,880 paces N. and 1,720 W.) is an oval mass of the rock which is rich in epidote. As exposed this mass is ten inches wide and fifteen inches long, but more of it evidently exists under the water. In the amygdules of this mass of rock metallic copper is abundant.

[1] See p. 16.

At the Copper mine dam on Crotty brook, in the S. W. ¼ of Sec. 6, three pits were sunk perhaps thirty years ago. The rock thrown out is a fine grained reddish diabase with amgydules of chlorite and quartz. Some of the rock is rich in epidote. None of the material examined showed any copper, although it is not unlikely that this mineral occurred in the epidotized parts of the rock and thus attracted exploration at this place. This is the only locality on the St. Croix range where any serious prospecting for copper seems to have been carried on.

T. 44 N., R. 14 W.

The only exposures noted in this township outside the area shown in the geological map (plate VII) are in Secs. 28, 29, and 32. In the last section (400 paces N. and 1,505 W.) is a ridge of medium grained reddish diorite, which is in places slightly porphyritic with feldspars. This rock contains a few metallic-appearing particles which might be mistaken for copper, but which are of some micaceous mineral that has developed in the alteration of the rock. Similar rock, most probably of the same mass, occurs to the southwest (15 paces N. and 1,845 W.) in the same section and also forms a prominent ridge which runs northeast and southwest through the center of Sec. 28.

In the N. W. ¼ of Sec. 29 are three exposures of melaphyre. These are near the east bank of the Tamarack river and a short distance above the buildings at the Tamarack farm.

T. 43 N., R. 14 W.

There are many exposures of melaphyre in this township and a number of amygdaloids in Secs. 2, 11, and 16. In the last section (260 paces N. and 1,040 W.) is an outcrop of amygdaloidal porphyry very similar to the porphyry noted on the Moose river in Sec. 2, T. 44 N., R. 13 W.[1] The two outcrops are in about the same stratigraphic position and perhaps represent one flow.

On the south line of Sec. 22, (1,235 paces west of the southeast corner of this section) is an exposure of reddish amygda-

[1] See p. 27.

loid which has epidote, chlorite and abundant calcite in the amygdules. Some malachite, which is undoubtedly an alteration product from native copper, occurs in these amygdules.

T. 43 N., R. 15 W.

Along the Tamarack river in Secs. 10, 15, 16, 20, 21, and 29 are a number of exposures of amygdaloidal rocks. Similar rocks occur on the Spruce river in Secs. 8 and 17. On the east bank of the former stream in Sec. 16 (about 795 paces N. and 900 W., and extending for 50 paces down stream) is some hard reddish diabase with amygdules holding chlorite, calcite and quartz. In some of the amygdules is also metallic copper. The coarser parts of the rock show luster-mottling. Farther down the river in the same section are four other outcrops, the most southern (400 paces N. and 1,130 W.) of which is of rock similar to that just mentioned. Here a small piece of native copper was found in one of the amygdules.

In Sec. 29 three exposures of melaphyre occur on the east bank of the Tamarack river. These probably belong to the same layer, which is quite likely the southwestern continuation of the layer exposed in three places in Sec. 29, T. 44 N., R. 14 W., mentioned above.

T. 42 N., R. 15 W.

Along Chases brook in Secs. 9 and 16 are some interesting exposures. In the latter section (1,840 paces N. and 1,050 W.) is a mass of coarse melaphyre forming a barrier across the stream. The augite crystals in this rock are at times an inch in diameter. Further up the stream in Sec. 9 (1,479 paces N. and 537 W. and extending northward to the north line of this section) are a series of amygdaloidal rocks. In the upper part of several of these flows native copper occurs.

CHAPTER III.

THE DOUGLAS COPPER RANGE.

This name is applied to the belt of copper-bearing rocks which are exposed along the hill range that marks the northern limit of the Lower Keweenawan rocks in Douglas county. The most important parts of this range are shown in detail on the accompanying geological maps, plates VIII and IX. Outside of the area of these maps there are very few rock exposures. Along this hill range to the east of Douglas county no outcrops of the traps have been reported, while to the west of this county some outcrops occur in Minnesota.

In some particulars the rocks of the Douglas range differ from those of the St. Croix range: (1) Prehnite is much more common on the former than on the latter. (2) The melaphyre belts, which are so characteristic a feature of the latter range, are lacking on the former, although there are in a few places rocks which approach rather closely to the typical melaphyres of the southern range. (3) On the Douglas range intrusive rocks are in places abundant, while they are practically lacking on the St. Croix range, unless some of the melaphyre belts should prove to be of this nature. These intrusive rocks consist of diabases, gabbros, granites, and syenites. The gabbros and syenites, which approach the gabbros in composition and which may be parts of the same general magma, are the most common of these intrusive rocks. On the west the intrusive rocks were first noticed at Pilot mound in Sec. 15, T. 47 N., R. 13 W. East of here they occur in abundance along the Aminicon river in many places between Rockmont and the southern limit of the Lake Superior sandstone. Some of the intrusive rocks are seen along the Middle river, especially in Sec. 2, T. 47 N., R. 12 W., and a bold knob of gabbro and associated rocks exists in the northern part of the N. W. ¼ of Sec. 25, T. 48

N., R. 12 W. The more acid of these intrusive rocks (granites and syenites) are in general of later date than the gabbros.

The strike of the lava flows on the Douglas range is northeast and southwest toward the western end. On going eastward the strike gradually becomes more nearly east and west, and at the eastern part of the range has this latter direction. The strike is approximately, but not exactly, parallel to the fault line which separates the traps from the Lake Superior sandstone to the north, the direction of the fault averaging a little more nearly east and west than does the strike which is inclined more toward the east-northeast and west-southwest. Thus in going from the eastern end of the range towards the west, one passes over lower and lower, and consequently older and older, flows.

SPECIAL DESCRIPTIONS.

Serious prospecting for copper has been carried on in the rocks of the Douglas range at intervals for over fifty years, and there are indications of some prehistoric attempts at copper mining. The history of these explorations has already been published by the Wisconsin Survey,[1] and the present preliminary report does not attempt to duplicate these descriptions. Below will be found brief accounts of the various locations where explorations for copper have recently,—mostly in 1898 and 1899,—been carried on.

The Culligan Location.

Explorations at this place have been made in the S. W. ¼ of Sec. 29, the S. E. ¼ of Sec. 30 and the N. E. ¼ of Sec. 31, T. 47 N., R. 14 W. In Sec. 30 the most work has been done and here are four test pits, which were filled with water when the examination was made. The pits are located along a small creek near the southeast corner of this section. One pit is reported to be thirteen feet in depth, the lower three feet being in rock. Another one is also thirteen feet in depth, while another is thirty feet deep, the lower seventeen being in rock. The material thrown out of these pits is all highly brecciated and some

[1] E. T. Sweet. Geol. of Wis., vol. III, pp. 358–362, 1880.

of it shows slickensided surfaces. On some of this material there are greenish stains which resemble malachite. These pits are regarded as located near the junction of the traps and the Lake Superior sandstone.

In Sec. 29 (770 paces N. and 1,150 W.) a shallow trench has been dug and the rock thrown out is mainly a greenish gray, hard amygdaloid. The amygdules are small, but numerous, and most of them contain quartz. Many of the amygdules hold native copper. Water in the trench prevented a careful examination. The copper-bearing belt of rock is reported to be five feet in width. If the rock thrown out is a fair sample of this belt,—and such seems to be the case,—this flow ought to be prospected more fully.

Along the creek in the N. E. ¼ of Sec. 31 there are exposures showing several flows which in some places carry copper both in the amygdaloidal parts of the rock and in small veins. The bed richest in copper has been struck in a test pit (1,697 paces N. and 113 W.), which passes through about four feet of hard, greenish brown, barren rock and then strikes an amygdaloid rich in epidote. This last rock carries considerable native copper. Many of the amygdules are completely filled with the metal, which also occurs in small seams. The exploration has not been carried far enough to determine how extensive this copper-bearing rock is, in fact the amygdaloid which carries the copper has been penetrated for only a few inches. The locality was visited again later in the season, but practically no more work had been done. This copper-bearing flow, like that mentioned above, ought to be exploited more fully. A little more work would determine whether the parts already exposed were fair averages in copper content, or were richer or poorer than the rest of the copper-bearing amygdaloidal portion of the flow. And at the same time the thickness and probable extent of the copper-bearing rock could be determined. These prospects in Secs. 29 and 31 are more encouraging than those in Sec. 30, where most of the work has been done on this property.

The Copper Creek Location.

This property includes the S. W. ¼ of Sec. 14 and the S. E. ¼ of Sec. 15, T. 47 N., R. 14 W. In former years considerable work was done here and several test pits and shafts were sunk and strippings made in the vicinity of the junction of the two branches of Copper creek. Unfortunately the information gained by this work has been lost, or is not available. During 1899 work was resumed again, mainly in different places from the old work.

Near the junction of the creeks there are a series of flows which strike approximately northeast and southwest. The dip is from 54° to 62° towards the southeast. The flows have amygdaloidal upper parts and in several cases, at the junction of two flows or in the upper part of a flow, are fractures whose dips correspond with the dip of the flows. Commonly along the fractures there is some brecciation. The broken parts of the rock are cemented by vein material,—quartz, calcite and prehnite,—and it is in this vein material that most of the copper occurs, although it is also found in the amygdules.

On the main stream, south of the junction, several flows are seen. In the upper part of one of these (159 paces N. and 43 W., Sec. 15) and the lower part of the next upper flow native copper occurs in amygdules. The copper-bearing bed is about a foot in thickness. On the high ground between the two creeks and south of their junction is a pit (233 paces N. and 41 W., Sec. 15) which is perhaps 50 feet in depth, but now is, like all the others, filled with water. The pit slopes at an angle of 60° towards the south-southeast. To the northeast is a trench running along the junction between two flows,—probably along the lower side of the flow in whose upper surface is the pit just mentioned. Thrown out of the pit or the trench is a quantity of rock which can be termed copper ore. It is brecciated rock cemented by quartz, calcite, prehnite, and some native copper. The brecciation is evidently along a fracture between two flows, for the rock is in part the dense fine grained portion from the base of a flow and in part the porous amygdaloidal portion of the top of a flow.

To the east of the main creek and north of the junction of the streams are several pits and in one place a tunnel. From what can now be seen these pits do not show as encouraging prospects as that just mentioned.

On the west side of the main stream, just north of the junction of the two streams, is a perpendicular rock face which has been exploited recently. The rock is in many places brecciated and along the broken sides of the fragments are slicken-sided surfaces. In some very irregular and limited areas the brecciation is more intense and the broken rock is cemented by nearly pure white calcite, and in this calcite is some native copper in the form of fine wires,—averaging less than a thirty-second of an inch in thickness. In addition to the calcite there is here also quartz and prehnite, both in amygdules and in fissures. The copper here is not so abundant as at the pit described above.

On the eastern of the two creeks there are a number of exposures, and at one of these (245 paces N. and 1,900 W., Sec. 14) is a brecciated belt which appears to be parallel to the dip. This belt is from one and a half to two feet in width and consists of rock fragments cemented by vein material, which here is mainly quartz and prehnite. The exposure is near the bed of the stream, and above this belt of broken rock is a highly epidotized area, evidently of the same flow. In the vein material is native copper, commonly in wire-like forms; these wires appear to be coated by native silver.

Later in the season this locality was visited again; the vein had been uncovered for a distance of thirty feet. It retained an approximately uniform width,—one and a half to two feet,—but was not as rich in copper as in the place where it was first uncovered.

On the northern brow of the high hill in Sec. 15 (480 paces N. and 500 W.) a pit has been sunk along the top of an amygdaloidal flow. The rock is a brown-weathering, reddish diabase. The south wall of the pit is the bottom of the next overlying flow. The strike and dip at the pit are rather anomalous, the former being N. 30° E. and the latter 78° towards the south of this. In this immediate vicinity a chance was had to measure the

strike and dip along a larger distance than could be obtained at the pit; the strike is N. 20° E. and the dip averages 70° towards the south of this. The upper three feet of the flow exposed in this pit contain most of the ore, although it occurs in smaller amounts through a thickness of twelve feet. The ore consists of two metallic minerals which have altered considerably. One of these is of a silver white color but has largely changed to a rusty brownish material. In the field this mineral was thought to be a nickel sulphide. The other mineral is regarded as a copper sulphide now almost completely changed to the green carbonate, malachite, which not only occurs in the amygdules but also exists as green stains along cracks. This pit is in similar rock, and near the same horizon stratigraphically, as another pit which was sunk for nickel several years ago about half a mile farther northeast (935 paces N. and 1,790 W., Sec. 14).

The Fond du Lac Location.

Prospecting at this location has been carried on in the N. E. ¼ of Sec. 8, T. 47 N., R. 13 W. In former years two deep pits were sunk here, called the Stewart and the Parker shafts. The former is about 400 paces northeast of the latter. In 1899 a considerable amount of stripping was done on this property, and several shallow pits and trenches were made in the rock. This work was of such a nature as to expose a large surface of the copper-bearing amygdaloids; in fact the work here has resulted in an examination of a larger amount of rock in which copper might occur than at any other of the recent explorations on the Douglas range.

At the brow of the hill range, crossed by the road on the east line of Sec. 8, is an exposure of hard, reddish, flinty rock which has been much fractured. The fractures are frequently healed by calcite. This exposure is 245 paces south of the northeast corner of Sec. 8, and other exposures of the same rock occur both to the west and to the east. About 100 paces west of the road a cross cut has been made from the rock just mentioned south for 100 paces across some amygdaloidal flows.

Trenching at the Fond du Lac Mine. N. E ¼ Sec. 8. T. 47 N., R. 13 W.

The Stewart shaft (1,400 paces N. and 345 W.) is said to be 65 feet deep. At the time the Survey parties examined it, it contained water to within about 25 feet of the top. The shaft goes down along a vein-like mass of rock which dips southward at an angle of 35°. The country rock is here a medium grained reddish diabase and the rock of the vein-like mass is a coarser grained diabasic rock which has been highly charged with epidote. The latter rock at the shaft varies from 10 to 18 inches in thickness. It can be traced, as exposed in strippings, almost continuously for 100 paces to the east of the shaft and for 200 paces to the west. Towards the east it becomes smaller and where last seen is about six inches in thickness. This vein-like mass appears to be a sheet of igneous rock which has been intruded along a fissure in the country rock, the fissure practically coinciding in direction with the dip and strike of the inclosing rocks. The copper content of this rock varies considerably at different points; in some places no copper at all is seen, at others this metal is quite abundant.

The flow, in which is the vein-like mass of rock just described, is markedly amygdaloidal at its upper surface. About 200 paces west of the Stewart shaft a cross-cut has been made from this flow south for over 100 paces. One of the rocks struck in this cross cut is a melaphyre which approaches in coarseness and general characters the characteristic melaphyres of the St. Croix range. Near the north end of this cross cut, and apparently in the upper part of the same flow, in which is the Stewart shaft, is a test pit. Here the amygdaloidal upper part of the flow has a horizontal breadth of about 18 feet. Pieces of sheet copper are reported from this place. These occur in seams in the rock, the seams being parallel with the dip. The specimens from this place seen by the writer were about one-eighth of an inch in thickness and from two to three inches across. This amygdaloidal layer is known as the Admiral Dewey vein or lode.

The Parker shaft (1,060 paces N. and 520 W.) is said to be 80 feet in depth. It goes down on the junction between two flows and slopes 22° to 38° toward the south. The plane of division between the two flows is the foot wall of the shaft, as

nearly as could be seen, the shaft being practically full of water when the examination was made. The upper part of the lower flow here is amygdaloidal, the amygdaloidal portion being ten to twelve feet in thickness. At the shaft and just to the west, where some trenching has been done, this amygdaloid carries copper. The upper flow at the shaft is also amygdaloidal and at one place (1,010 paces N. and 615 W.) west of the shaft a trench has been cut across the amygdaloidal part, which here has a horizontal width of 18 feet. (See plate X.) This is known as the Little Maude vein. In places the amygdaloid has been fractured, probably along a plane parallel with the surface of the flow, and the fractures have been filled with quartz, prehnite, calcite and epidote. With these minerals is considerable native copper, which has partly altered to malachite. Small nuggets of copper, weighing several ounces, are reported from this place.

To the south of this one or two other flows have been uncovered; they bear copper in small amounts, but not as much as occurs in the Little Maude vein.

The Catlin Location.

In the S. E. ¼ of Sec. 34, T. 48 N., R. 13 W., some exploratory work has been done. This consisted of blasting in a few places and the sinking of two test pits. One of these is on the St. Croix road (590 paces N. and 120 W.) and strikes the upper part of a porphyritic amygdaloid. The other (50 paces N. and 620 W.) is on a small stream. The rock here is a reddish medium grained diabase.

The Starkweather Location.

This property has been known as the Edwards mine and also as the Wisconsin mine.[1] It is situated in the N. W. ¼ of Sec. 2, T. 47 N., R. 13 W. In the N. W. ¼ of this quarter section several pits, or shafts, have been sunk. During the time the Survey parties were in this district there was no work being done at this locality, and the pits were full of water. Consequently no careful examination could be made. It is evident that the

[1] E. T. Sweet. Geol. of Wis., vol. III, p. 360, 1880.

property is crossed by a series of amygdaloidal flows and that some of these are copper-bearing. The rock thrown out of the pits is in general of four kinds: (1) dense diabasic rock evidently belonging to the base of a flow; (2) amygdaloid from the upper part of a flow; (3) fine grained, vein-like material, probably acting as a cement to the broken up upper surface of a flow; (4) brecciated rock cemented by vein material which is mainly quartz, calcite, epidote and a red mineral (probably laumontite). Native copper, altered in places to malachite, occurs in the amygdules, and also in the vein cement of the brecciated rock, but more commonly in the latter. Most probably the richest specimens of the copper-bearing rock have been taken away by people who not uncommonly visit this location. Nothing can be said, from the examination it was possible to make, concerning the thickness and richness of the copper-bearing rock. The general relations and manner of occurrence of the copper appear to be the same as in the other localities already described.

The Aminicon Location.

This is situated in the N. W. ¼ of Sec. 11, T. 47 N., R. 13 W. Some stripping and blasting has been done along the bold rock hill that extends northeast and southwest through this quarter section. The most serious work was done in sinking a test pit (1,625 paces N. and 1,110 W.) at the base of this hill near its northeastern end. This pit goes down on a small vein, which is from one-fourth to two inches in width. It has slickensided surfaces and is filled mainly with calcite, quartz, talc and soft clay selvage. The vein strikes nearly east and west and dips 75° to the north near the surface, but the dip varies to more nearly vertical a few feet below the surface. It is the expectation of the owners that this vein will widen out and become copper-bearing some feet below the surface.

Just to the north of this pit is an irregular vein, from two to eighteen inches in width. It is about vertical, strikes north and south and towards the south splits into two veins. The vein is a brecciated portion of the rock cemented by quartz, calcite and red feldspar. There is also chalcopyrite, chalcocite and

malachite in the vein. The latter is most probably secondary, possibly after native copper, which is reported from this vein. Chalcopyrite and chalcocite also occur in amygdules in several places along this hill.

The North Wisconsin Location.

This property is located in the S. W. ¼ of Sec. 3 and the N. W. ¼ of Sec. 10, T. 47 N., R. 12 W. The outcrops noted at this place and the prospecting done is confined to the immediate vicinity of the line between these sections and does not extend over 200 paces eastward from the west corner post on this line.

Along the Middle river, just below the dam, are exposures of several flows which are markedly amygdaloidal in the upper parts, the amygdules being frequently of laumontite. Here, on the east side of the river, a pit has been sunk. This is said to be 51 feet in depth and has drifts running from the bottom. In these drifts considerable copper has been reported. At the time this property was examined the pit was full of water. On the west bank of the river is a vein-like form, six inches wide, cutting one of the flows. The vein rock is hard, very fine grained, and greenish to yellowish in color. It contains specks of native copper and there are malachite stains along the cracks.

A shaft (22 paces N. and 1,853 W., Sec. 3) is being sunk in one of the flows. This is east of the dam, and just to the south of the shaft are three pits full of water. The shaft slopes about 62° to the south. It is seven and a half by twelve feet, inside the timbers, and in August, 1899, had reached a depth of about 80 feet. At this time machinery for hoisting and drilling was being put in. (See plate XI.) The shaft goes down in the amygdaloidal upper part of a flow, and this rock carried native copper in the amygdules, although not so abundantly as reported from the pit, mentioned above, on the east bank of the river.

The Astor Location.

No extensive work has been done on this property, which is in the N. W. ¼ of Sec. 28 and the N. E. ¼ of Sec. 29, T. 48 N., R. 10 W. In the former section (1,275 paces N. and 1,820 W.)

The North Wisconsin Mine. S. W. ¼ Sec. 3, T. 47 N., R. 13 W.

is a pit which at the time of the examination had not certainly reached the solid bed rock, although very close to it. The material thrown out was practically all of one rock which had been brecciated and cemented by vein minerals. About 150 paces north of this pit and at a little falls on a small stream is an exposure which shows evidence of having been explored a number of years ago, and just to the north of it is a filled test pit. The rock here shows an epidotized area, two to four feet in width. In this, and in cracks adjoining, is chalcopyrite, and native copper is also reported.

To the west in Sec. 29 there are a number of exposures, usually of amygdaloidal rock which bears chalcopyrite. In one locality there seems to be evidence of some very ancient attempts at prospecting, the ground now being covered by large trees which have grown up since this was done.

The Percival Location.

The principal explorations on this property have been in the N. ½ of S. W. ¼ of N. E. ¼ of Sec. 27, T. 48 N., R. 10 W. Considerable work was done here a number of years ago, and work has been actively resumed recently.

An old pit (1,303 paces N. and 1,110 W.) west of the present shaft goes down perhaps 30 feet. The pit was sunk to investigate a vein which trends nearly east and west. The vein is from one to ten inches in width and is mainly of calcite. It carries some native copper. Just to the east of this is a stripping which exposes the same vein. Prospecting on at least two veins of similar character, also carrying copper, has been done in several places a short distance east of this pit. One, at least, of these veins differs from the other veins met in the explorations already described in that it is not parallel to the dip and strike of the beds of igneous rock in which it lies. This vein dips to the north at an angle of about 65°, while the dip of the flows is toward the south. It is not unlikely that the other veins at this locality also fill fractures which do not lie parallel with the surfaces of the flows.

The principal work at this locality is now being done at a

shaft (1,432 paces N. and 722 W.) which is eight by six feet in size. Drilling, hoisting, and pumping at this shaft are done by steam, this being the only locality on the Douglas range where machinery was used during the summer of 1899. The shaft goes down in the amygdaloidal part of a flow, and the hanging wall of the shaft is the bottom of the next higher flow. The dip of the upper part of the shaft is about 40° towards the south, but towards the bottom it becomes steeper, being 46°. In August, 1899, the shaft had reached a depth of 90 feet. The amygdaloid penetrated by this shaft contains the minerals common to the amygdaloids of the district, but is noticeable for the laumontite and the large amount of prehnite. This rock is in places highly charged with epidote, the masses rich in this mineral being, as far as can be seen, roughly spherical in shape. Several of these epidotized masses have been found in the shaft. These areas vary in size, but the writer did not see evidence that any of them yet found here are over six feet in diameter. It is in these highly epidotized masses that the chief part of the copper occurs, and at times specimens from such parts of the rock are very rich in this metal, which occurs in the amygdules, in cracks and in irregularly disseminated particles.

About 200 and 400 paces east of this shaft are pits probably sunk on the same flow. At each the amygdaloid contains considerable quantities of laumontite. Some stripping has recently been done on a small stream about a quarter of a mile northeast of the shaft.

CHAPTER IV.

THE COPPER DEPOSITS.

In this chapter it is proposed to present a brief discussion concerning the mode of occurrence of the copper, where to search for copper and the value of the deposits.

MODE OF OCCURRENCE.

The copper found in Douglas county occurs mainly as the native metal. At times this has suffered alteration, where exposed to the agents of weathering, to the green carbonate, malachite, and less frequently to the blue carbonate, azurite. These two minerals occur only in small amounts. In many places on the Douglas range copper occurs in the form of chalcopyrite (a brass-yellow mineral composed of sulphide of copper and sulphide of iron) and in smaller amounts as chalcocite (a dark, almost black mineral composed of sulphide of copper). In no places in this district have the last two minerals been found in sufficient quantities to attract exploration, nor does it seem probable that deposits of these minerals of economic importance will be discovered. In order to be of value as ores chalcopyrite and chalcocite must occur in greater abundance than is necessary for the native metal. Thus the deposits of copper which are liable to prove of economic value are those in the native state.

Native copper occurs in this district in three ways:—(1) in amygdules, or in pseudamygdules, or in small particles scattered through the rock; (2) in minute seams; (3) in veins.

The commonest mode of occurrence is in amygdules where the copper partially or completely fills the amygdaloidal cavities. The minerals associated with this metal in the amygdules, and imbedded in which the copper frequently occurs, are quartz, calcite, prehnite and epidote. Commonly at least two of these minerals are present in any copper-bearing amygdaloid.

An exceedingly abundant accompaniment of the copper is epidote. Very frequently along seams or in areas of indefinite shape the rocks have been highly charged with this mineral. Commonly these epidotized masses are of roughly spherical form and vary in diameter from an inch to a few feet. With the epidote in such masses is much quartz, especially in the amygdules. The copper occurs in the amygdules and also scattered throughout the rock. Many of the occurrences of copper on the St. Croix range are in epidotized parts of the rock, and the same is true on the Douglas range, especially at the Percival location where the richest parts of the rock are those highly charged with epidote.

Prehnite is comparatively rare on the St. Croix range, but is known from at least two places. One of these is on the Moose river in Sec. 2, T. 44 N., R. 13 W., where this mineral occupies the amygdules in common with the copper.[1] The other locality is on Crotty brook near the center of Sec. 30 (1,120 paces N. and 995 W.) in the same township. On the Douglas range, however, prehnite is a common accompaniment of the copper, as for instance at the Copper Creek and the Percival locations where this mineral is abundant in the copper-bearing rock.

In minute seams in rock, which is otherwise copper-bearing, there are at times films or thin sheets of this metal. These are most common in places where the rock is highly charged with epidote.

The true veins thus far discovered in the copper-bearing rocks of Douglas county are most frequently parallel to the layers of rock. These veins occur most commonly in the upper amygdaloidal parts of the flows, and frequently along these veins there has been a brecciation of the adjoining rock. Where this brecciation has not taken place the vein is narrow, commonly only a few inches in width, but where the adjoining rock is brecciated the vein minerals have cemented the rock fragments and the total thickness of vein material may be increased to a few feet. The minerals of these veins are chiefly quartz, calcite and prehnite. Copper occurs in small irregular pieces scattered through

[1] See p. 28.

the vein material. One peculiar occurrence of copper in these veins is at the Copper Creek location where this metal is in wire-like forms penetrating either calcite or quartz. In one vein these wire-like pieces of copper appear to be covered by a thin coating of native silver.

A few small veins have been found which cut the rocks at a marked angle to the different layers, as at the Percival location.[1] These contain the same minerals as the other veins already mentioned and also carry copper.

Mention should also be made of two kinds of vein-like forms which sometimes occur in the copper-bearing rocks. The first are found in the upper parts of certain lava flows and consist of very fine grained flinty rock, which is red to yellow in color. This exists in vein-like forms an inch or more in width, and sometimes carries copper, as on Crotty brook in Sec. 7, T. 43 N., R. 13 W., on the St. Croix range, and at the North Wisconsin location on the Douglas range. The second kind of vein-like form occurs at the Aminicon location. Here a fracture is filled with material, which has likely fallen into a crack in the top of a lava flow, and this material was later cemented by certain minerals. In this vein are chalcopyrite and chalcocite; native copper has also been reported.

The vein-like form at the Stewart shaft at the Fond du Lac location is not a vein, but an intruded layer of igneous rock which has been epidotized and impregnated with copper.

WHERE TO SEARCH FOR COPPER.

In prospecting for copper operations should be confined to the area underlain by the igneous rocks of the Lower Keweenawan (see geological maps, plates I, VII, VIII and IX). There is very little probability of copper being found in any considerable amount either in the sandstones of the Upper Keweenawan or in the Lake Superior sandstone. In the northern belt of Lower Keweenawan rocks the search should be confined within a few miles of either the southern or the northern boundary of the traps,—not because there is no copper in the intervening dis-

[1] See p. 41.

trict, but because outcrops are so scarce that the chances of discovering a copper-bearing layer are very much less. The hills and the streams should be visited, for in these two places outcrops are more likely to occur. An outcrop of some peculiar kind of rock may sometimes be located by tracing fragments of this rock, which have been distributed by a stream or by glacial agencies, back to their original source. In doing this it must be borne in mind that the glacial movement in this district was from north to south or from northeast to southwest.

It is not necessary here to go into a discussion of the origin of the copper deposits. It is only needful to state that the copper, while it may have been originally disseminated in very minute particles throughout the igneous rocks, has been deposited in its present position by circulating waters. Those areas in which the water was most free to circulate, other things being equal, would be areas in which the most copper was deposited. Thus it is evident that the deposits of this mineral are to be searched for in those parts of the rock which were actually loosely textured or which were crossed by fractures. And such loosely textured portions of the rock are the amygdaloidal upper parts of the lava flows. When these were also fractured, they became still better places for the deposition of copper.

The copper deposits of Douglas county most commonly occur in these upper amygdaloidal parts of the lava flows. The criteria by which a separation can be made between two flows, and consequently the upper part of one flow located, have already been given.[1] When such an amygdaloid part of a flow has been located, careful search should be made for copper both in the amygdules and in any veins or fractured parts of the rock. At times at the surface the native copper is not discernible, and its presence may be detected by the green and blue alteration products or stains, malachite and azurite. Areas where the rock is highly charged with epidote, i. e., areas of a yellow or yellowish-green color, should be searched for particularly, as in these copper is likely to occur.

When the upper amygdaloidal part of a flow has been lo-

[1] See pp. 12-15.

cated, the following conditions may be of service in determining whether it should be prospected farther than can be done by a careful examination of the surface and of those parts which can be easily broken off with a hammer or pick: (1) The actual presence of native copper, or of the alteration products. (2) The loose texture of the rock, i. e., the presence of large amygdules near together or of very numerous small ones. (3) A layer of such amygdaloid which is several feet in thickness. (4) The presence of fractures or veins in the rock, in which are the usual vein materials. (5) The presence of areas which are highly charged with epidote. There is very little chance of success in further prospecting in an amygdaloidal layer unless at least one, and preferably several, of these conditions are fulfilled. And to this may be added that, other things being equal, such an amygdaloidal layer which immediately underlies, or immediately overlies, a thick non-amygdaloidal layer of rock, or which lies between two such thick layers, furnishes a more promising place to prospect.

During the Glacial period practically all the decayed or weathered rock was removed from the traps of the Keweenawan, leaving them fresh and sound except for such changes as had gone on at a considerable distance below the surface. Post-Glacial weathering commonly extends only a fraction of an inch from the surface, and only in a few places, such as in some fissured and very porous rocks, do the effects of weathering reach several inches or possibly a few feet below the surface. The deposits of copper were formed very long ago and since their formation very many feet of rock have been removed by erosion in this district, so that what is now exposed at the surface was once deeply buried. With these two facts in mind,—i. e., the slight amount of weathered rock and the presence at the surface today of rock which was once deeply buried,—it becomes clear (1) that there is just as much likelihood of deposits of copper being found at the surface as at a distance of many feet below the surface, and (2) that such deposits are fully as liable to be rich at the surface as many feet farther down. The practical application of these principles will lead, not to deep

shafts for exploratory purposes, but to the less expensive surface explorations, especially where the rock can be uncovered by the removal of only a few feet of overlying unconsolidated material. Stripping, accompanied possibly by shallow trenches or test pits in the rock, will bring to view a much larger area of a given copper-bearing bed than the same amount of energy and money expended in sinking a deep test pit or a shaft. Where the drift material overlying the bed rock is so thick as to make stripping very expensive or impossible, recourse must be had to a shaft or deep test pit, but even here the copper-bearing rocks can be explored more easily by running drifts and cross cuts from the bottom of a shallow shaft than by sinking a deep shaft. Exploratory shafts should be sunk, not in a vertical direction, but along the dip of the lava flows. Very commonly it is advisable to sink the shaft in the very top of one flow, using the bottom of the next overlying flow as the hanging wall of the shaft. But, as long as there is so much copper-bearing rock which can be explored on or very near the surface, it is not advisable to sink shafts until the surface and shallow explorations have brought to light deposits which have considerable extent and value.

The advantage of surface or shallow explorations is spoken of here because there is a rather prevalent opinion, among those who are engaged in exploratory work for copper in Douglas county, that rich copper ore is not to be expected at the surface, that any copper-bearing layer will grow richer with depth, and that a given layer is not satisfactorily proved to be worthless until it has been followed to a depth of at least 200 or 300 feet from the surface. There is absolutely no known reason why the copper deposits in Douglas county should increase, or decrease, in richness with depth. A given amount of a copper-bearing bed explored in a horizontal direction is just as reliable an index of the contents of the bed as the same amount of exploration in a vertical direction, and the former is usually by far the cheaper method of exploration. In fact if, as is reported, the copper deposits in Michigan are elongated more in a vertical (i. e., in the direction of dip), than in a horizontal

direction, the ore at times occurring in ore chutes, a given amount of horizontal exploration is worth more than the same amount of vertical exploration. During a visit to the copper district of Keweenaw point the writer made it a particular point to inquire concerning this idea of a deposit's increasing in richness with depth. The question was put to mine superintendents, mining engineers, and mining captains, and the invariable answer from these men, whose practical work and long experience rendered their statements reliable, was that this idea had no basis in fact; a given deposit might grow richer, or it might grow poorer, with depth; there was no rule.

In the description of the fault along the line of junction of the Keweenawan traps and the Lake Superior sandstone[1] attention was called to the marked brecciation of the traps for a considerable distance from the contact. Such a brecciated zone would form an excellent channel for circulating waters to pass through and might consequently be regarded as a very favorable location for copper deposits. As far as known, however, this brecciated zone has not furnished much promise in this line, and there is reason to think that it does not contain richer deposits of copper than can be found elsewhere. A probable explanation of this is that the most of the copper was deposited in its present position in the traps prior to the date of this fault, and that since the faulting there has been little copper deposition. A similar fault exists between the traps and the Lake Superior sandstone on the eastern side of Keweenaw point, and along this fault no important copper deposits have been found.

Large veins have not been discovered in the traps in Douglas county, but if such can be found they will furnish promising locations for exploration.

VALUE OF THE COPPER DEPOSITS.

As has already been stated, and as the foregoing description of the geology of Douglas county has confirmed, the Keweenawan traps of this district are the same in nature, in origin and in age as the copper-bearing rocks of Keweenaw point, and

[1] See pp. 17-20.

consequently might contain similar deposits of copper. In regard to the identity of the rocks of the two districts it may be well to quote certain statements made by Prof. R. D. Irving:[1]

It is therefore proper that I should insist here that this identification (of the bedded diabases and amygdaloids of the St. Croix Valley with those of Keweenaw Point) is also indisputable; and that it is so because of the absolute identity in nature and structure of the rocks of the two regions, and because the Keweenaw belts have been followed continuously from the eastern end of Keweenaw Point to the Saint Croix River.

In support of the first of these assertions, I have to advance the following facts. The predominant fine-grained basic rocks of the two regions are so completely the same in mineral composition, even to the alternation-products, that thin sections of rocks from the two districts placed side by side are not distinguishable from one another. The only approach to an exception to this statement is the somewhat greater prominence of prehnite as an alteration-product on Keweenaw Point than on the Saint Croix. The rocks of the two regions present precisely the same amygdaloidal, pseudamygdaloidal, and compact phases. The amygdules are made of the same minerals in both, associated in the same ways. Native copper occurs in the Saint Croix Valley in the same manner, and with the same associates as on Keweenaw Point. Here and there an exposure may represent a dike so far as can be perceived, but almost everywhere the Saint Croix Valley rocks present precisely the same bedded structure as seen in those of Keweenaw Point. This is displayed, not only in the common step-like contours of the exposures, but the individual beds may be readily separated from one another, each bed often showing sharply marked its upper vesicular and lower compact portions. Moreover, where the dip is high and the exposures are large, as on the Snake and Kettle rivers of Minnesota there is to be seen a continuous series of beds, in all many hundred feet thick and in every respect similar to the alternations which obtain on Keweenaw Point. The same interstratified porphyry-conglomerates and sandstones are met with in both regions, and in both regions carry at times native copper. Interbedded original felsitic porphyries also occur in both regions.

In support of the second assertion, as to the actual continuity of the Keweenaw Point and St. Croix rocks, I have to say, in the first place, that the evidence of this continuity is precisely the same for the distance between the Montreal and the Saint Croix, as for that between the Montreal and Keweenaw Point, or even the distance

[1] "The Copper-bearing Rocks of Lake Superior;" U. S. Geol. Survey, Monograph V, pp. 239-241, 1883.

between the eastern part of Keweenaw Point and its western portion at Portage Lake; that the continuity has never been disputed for the two latter distances; and that it should therefore be accepted at once for the first named distance. The evidence for all the distance between Keweenaw Point and the Saint Croix is just as strong as that ever appealed to to prove the continuity of geological formations anywhere, save in those very rare and exceptional regions where the rocks are completely bare. This evidence consists in the frequent recurrence, at short intervals, of the same kinds of rocks, with the same structure and stratigraphical arrangement; and such evidence is forthcoming in the present case. From Keweenaw Point to the Saint Croix, the formation has been traced mile by mile with a constant recurrence of precisely the same bedded basic rocks, with the same amygdaloidal and compact portions to the beds, of the same associated felsitic porphyries, of the same interstratified porphyry-conglomerates, and of the same native copper in veins, altered amygdaloids and conglomerates. The same division of the series into a Lower or prevailingly eruptive member, and an Upper or detrital member, is also everywhere present. From Keewenaw Point to the region of Long Lake, some even of the subordinate members are recognizable as continuous. For the particulars of this evidence, I refer to the detailed description of Foster and Whitney's report, of Vol. III of the Geology of Wisconsin, and of the present work; to the United States Land Office township plats; and to the collections of the Wisconsin Geological Survey, and of the survey made for this report. If this evidence does not constitute proof of continuity, then no geological formation in the United States has ever been proved to be continuous for more than a very few miles—rarely for more than a mile—except in the plateau region of the western territories.

Other members of the former Geological Survey of Wisconsin,—Prof. T. C. Chamberlin, State Geologist, and Messrs. E. T. Sweet and Moses Strong,—all agree with Prof. Irving in regard to the identity of the traps of Douglas county with those of Keweenaw point. In fact the actual identity of the rocks of these two districts is today regarded by all students of the geology of the Lake Superior region as established beyond a doubt.

With this fact established, and the actual presence of deposits of copper in these rocks also established, there remain only two important points to be determined concerning the value of the copper deposits under discussion. These points are the *richness* and the *extent* of the deposits.

The results of several analyses of copper-bearing rock from the St. Croix and the Douglas ranges are given below, the first two being from the former and the others from the latter range:[1]

I.	An average three pound piece of rock from the highly epidotized area on the Moose river in Sec. 14 (675 paces N. and 925 W.), T. 44 N., R. 13 W., described on page 27. Specimen No. 8,054....	0.51 per cent.
II.	Average of samples from the Moose river in Sec. 2 (765 paces N. and 870 W.), T. 44 N., R. 13 W., described on page 28. Specimen No. 8,072......	0.67 per cent.
III.	Average of samples of the small part of a flow exposed in the bottom of a test pit at the Culligan location in Sec. 31 (1,697 paces N. and 113 W.), T. 47 N., R. 14 W., described on page 33. Specimen No. 8,497................................	4.19 per cent.
IV.	Average samples from the ore thrown out from a pit or trench at the Copper Creek location in Sec. 15 (233 paces N. and 41 W.), T. 47 N., R. 14 W., described on page 34. Specimen No. 8,401......	0.29 per cent.
V.	Average samples from the brecciated belt at the Copper Creek location, described on page 35. Specimen No. 8,417[2]............................	0.35 per cent.
VI.	Selected samples from pit on hill top at the Copper Creek location, Sec. 15 (480 paces N. and 500 W.), T. 47 N., R. 14 W., described on page 36. Specimen No. 8,425[3]................................	1.60 per cent.
VII.	Selected four pound piece from the "vein" at the Stewart shaft on the Fond du Lac location, described on page 37. Specimen No. 8,764. See next analysis..................................	3.64 per cent.
VIII.	Same as last. In taking from No. 8,864 the forty grams for examination two pieces of metallic copper were found weighing 1.34 grams. To ascertain if this was an average sample another portion of forty grams was taken which gave.......	0.39 per cent.

[1] These analyses, except .. and XII, were made by Prof. W. W. Daniells of the University of Wisconsin. XII was made by Mr. George H. Ellis of Chicago and X by Mr. E. F. Burchard of Northwestern University.

[2] The copper here appears to be coated by a film fo silver, but a test for silver gave a negative result.

[3] Also tested for nickel, but with a negative result.

IX.	Average samples from a fractured vein-like area in the Little Maude lode, Fond du Lac location, described on page 38. Specimen No. 8,326........	0.99 per cent.
X.	Other samples same as last........................	1.25 per cent.
XI.	Average six pound piece from one of the highly epidotized areas in the shaft at the Percival location, described on page 42. Specimen No. 8,706.	1.37 per cent.
XII.	Same as last, one pound piece....................	1.21 per cent.

In regard to the richness of the deposits the foregoing analyses show that there are certain bodies of rock, as far as known of limited extent, however, which contain sufficient copper to be termed copper ore. Ore which averages one per cent. of copper will, with the present prices, under favorable conditions and economic working produce a profit. But such ore must occur in beds or veins several feet in thickness and of considerable extent vertically or horizontally, i. e., large amounts of the ore must be accessible. It should be borne in mind, however, that these analyses, while being in some cases analyses of the average of small masses of the rock, are in no cases analyses of average samples of a bed or vein which have been shown to be of any considerable extent. And just here is the last, and consequently the important, point to be established concerning the value of these copper deposits,—are any of them extensive enough to be worked at a profit? This is a question, not of theory, but of fact, and a perfectly conclusive answer to it can be had only as a result of extensive exploration. At the same time some light may be thrown upon it by a consideration of the results of the exploration already done and by a consideration of certain geological features.

As far as the results of the exploration which has been carried on thus far,—and there has been considerable of it,—were open to the inspection of the Survey, it can be stated that in no place was a deposit of copper, which was of sufficient richness, shown to be of any great extent. The results of some of the old explorations were not available, nor was it possible to investigate certain workings now filled with water, but the Survey parties were very freely allowed to investigate the workings in active operation. In several places a layer of sufficiently good ore one

or two, or possibly more, feet in thickness was exposed, but on following this a few feet along the strike, or in the direction of the dip, the copper content rapidly decreased. In layers, in which were highly epidotized masses containing copper in considerable amount, it was found, where full investigation was made, that these masses were of limited extent and that outside of them there was only a small amount of copper. On the other hand there were a few places where a small amount of a copper-bearing layer was exposed, and what was exposed was of a good quality of ore. In these cases further work is necessary to demonstrate the extent of this good ore.

One noticeable fact in the copper-bearing rocks of Douglas county is this irregular and uncertain distribution of the copper in any given bed. This "bunchy" nature of the deposits is also a characteristic of the Keweenaw Point district, where even the best copper-bearing layers are in places very poor in copper, and where in even the richest mines at times considerable barren rock is found. Because of this uncertain and sporadic distribution of rich rock in a given copper-bearing layer, it is clear that an investigation of such a layer at one point will show nothing conclusive either as to the richness of the layer.

It is a noticeable fact in the Keweenawan traps of the Douglas and St. Croix ranges that the flows are of small thickness and that in one locality several of these flows are copper-bearing. Thus in a given thickness of rock there are several amygdaloidal layers, in each of which copper is deposited in small amounts. It seems reasonable to state that, if in this same thickness of rock there had been but one amygdaloidal layer, this would have served as a place of concentration for the copper which is now scattered in several layers. This was in view when the statement was made that, other things being equal, an amygdaloidal layer between two thick non-amygdaloidal layers was a promising place to search for copper.[1] As far as the writer knows, the amygdaloidal layers in the best parts of the Keweenaw Point district are, in a given thickness of rock, much fewer in number than in the localities explored in Douglas county.

[1] See p. 47.

The absence of interbedded conglomerates in the traps on the north side of the syncline in Douglas county probably has no bearing on the question of the value of the copper deposits. The frequently reported finding of "float" copper in the drift should be noted, but these loose pieces of copper may have been transported by glacial ice from localities many miles distant.

The writer has attempted to give a calm and unprejudiced statement of the facts which bear upon the question of the value of the copper deposits on the Douglas and St. Croix ranges. These facts may be summarized as follows: (1) The identity of the rocks with those of Keweenaw point. (2) The presence of native copper. (3) The presence, in places, of sufficient copper to form an ore of value. (4) In most of these places exploration has shown that the rich rock is only of limited extent. (5) In a few places exploration has not gone far enough to show the extent of the rich rock. (6) The "bunchy" distribution of the copper in any layer. (7) The presence in a given thickness of rock of several amygdaloidal layers, rather than one layer. From a consideration of these facts it is, with our present knowledge, impossible to answer satisfactorily the question as to whether or not copper deposits of economic value will be found in this district, but to the present time no such deposit has been shown to exist.

NOTE. After this report was written some of the localities on the Douglas range were again visited (March, 1900). Explorations at the Copper Creek and at the Culligan locations have been carried forward to a small extent. At the Fond du Lac a shaft has been sunk on the Little Maude lode. At and just above the upper falls of Black river some blasting has been done in two copper-bearing layers. Just below Black River falls two tunnels are being dug. One of these is in the traps, but near the contact with the sandstone, and runs about parallel with this contact. The other cuts across the trap flows about at right angles to the strike. The results of these additional explorations do not make it necessary to alter any of the statements made in this report.

Recent explorations for copper in the southeastern corner of Douglas county, on the south side of the syncline of Keweenawan rocks and outside of the area studied by the Survey, are reported to show very encouraging prospects.

From

Wisconsin Geological and Natural History Survey.

E. A. BIRGE, Director. C. R. VAN HISE, Consulting Geologist.

BULLETIN NO. VI. ECONOMIC SERIES NO. 3.

PRELIMINARY REPORT

ON THE

COPPER-BEARING ROCKS

OF

DOUGLAS COUNTY, WISCONSIN.

BY

ULYSSES SHERMAN GRANT, Ph. D.,
Professor in Northwestern University.

MADISON, WIS.
Published by the State.
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Wisconsin Geological and Natural History Survey.

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